Exploring the MBL cloud and drizzle microphysics retrievals from satellite, surface and aircraft

Xiquan Dong, University of Arizona
Pat Minnis, SSAI

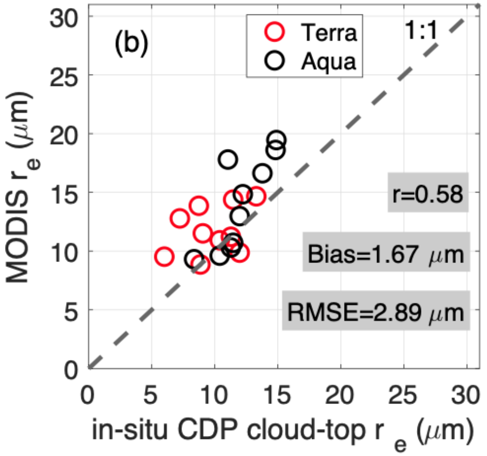
1. Briefly describe our newly developed retrieval algorithm using ARM radar-lidar, and comparison with aircraft data.

Wu et al. (2020), JGR

2. Can we utilize these surface retrievals to develop cloud (and/or drizzle) R_e profile for CERES team?

Re is a critical for radiation and aerosol-cloud-precipitation interactions, as well as warm rain process.

A long-term Issue: CERES R_e is too large, especially under drizzling MBL clouds

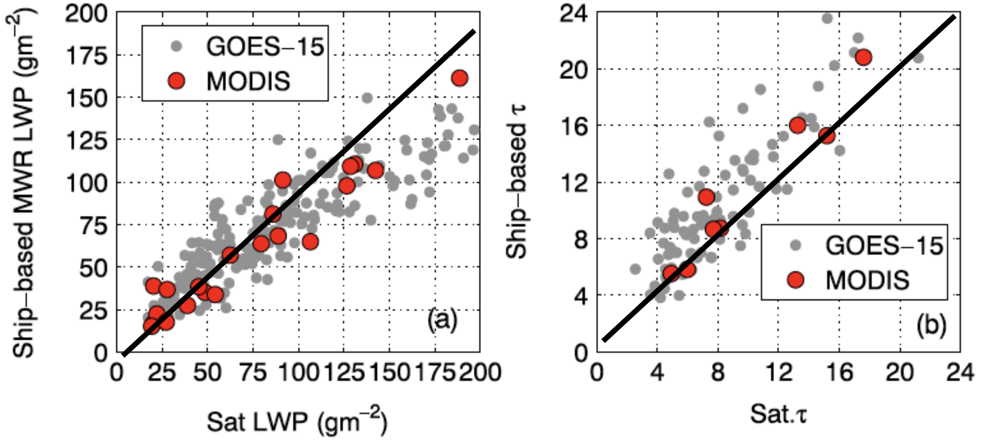


A/C obs in N Atlantic low clouds

CERES Re too large
Worse for larger Re

Painemal et al. 2020

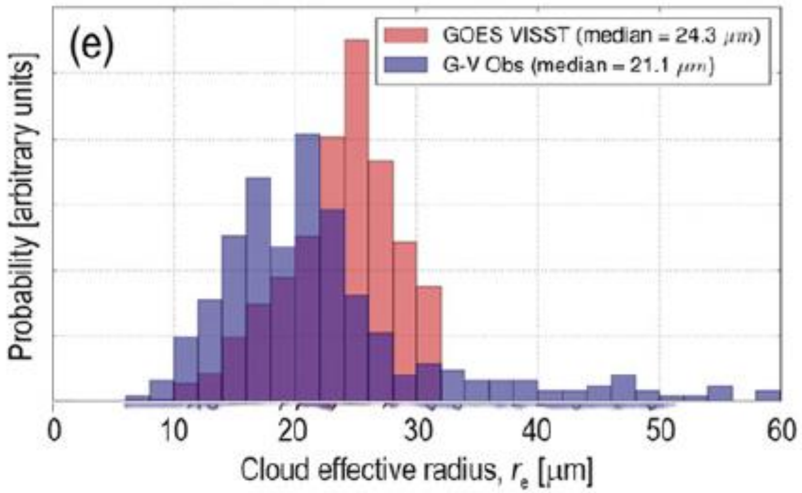
- **Cloud droplet size retrievals generally too high**
- **Especially large for Re(1.6, 2.1 µm)**
- **Cloud heterogeneity plays a role, but drizzle may also be a factor**
  - **Can we understand the impact of drizzle on these NIR retrievals and their differences with ground truth?**



CERES LWP high, tau low, due to large Re
Which will lead to high SW transmission at the surface and less albedo at TOA

Painemal et al. JGR 2017

A/C obs in thin Pacific Sc with drizzle



In thin drizzlers, Re is overestimated by 3 µm

Wood et al. JAS 2018

Profiles of MBL Cloud and Drizzle Microphysical Properties retrieved from Ground-based Observations and Validated by Aircraft data during ACE-ENA IOP

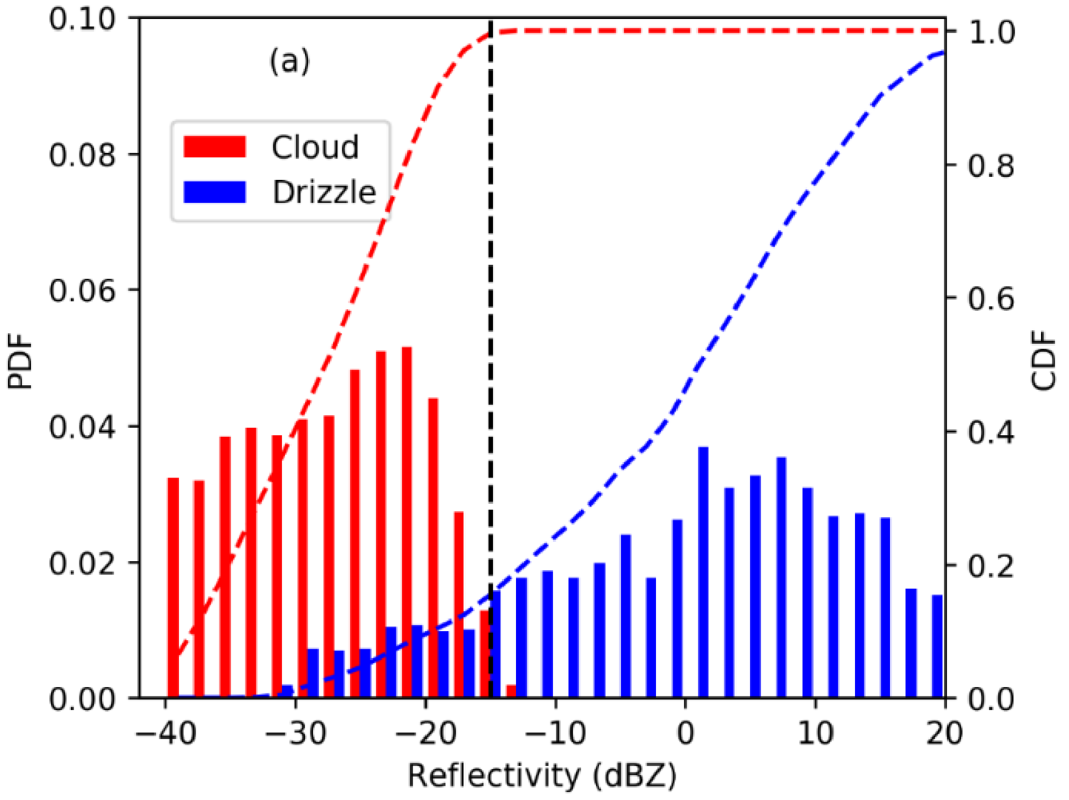
Radar reflectivity: $Z = \int_0^{D_{max}} D^6 N dD$

Challenge is to simultaneously retrieve both cloud and drizzle properties within an MBL cloud layer using radar-lidar observations because radar reflectivity depends on the sixth power of the particle size and can be highly weighted by a few large drizzle drops in a drizzling cloud

THE UNIVERSITY OF ARIZONA

Wu et al. 2020, JGR

Step I: Decompose cloud and drizzle reflectivity from KAZR Measurements



(a) Cloud droplets have max. reflectivity of ~-15 dBZ calculated from FCDP (2-50 µm) and drizzle reflectivity calculated by 2DS data (25-1000 µm)

(b) Find the height of -15 dBZ. The reflectivity above this height is solely contributed by cloud droplets

(c) $Z_{c,base} = Z_{above} - Z_{below}$, LWC_c increase linearly ➔ $\sqrt{Z_c}$ increase linearly $Z_d = Z_{obs} - Z_c$

Step II: Develop Retrieval methods

Retrieval:

$$\boldsymbol{x} = \boldsymbol{G}^{-1}\boldsymbol{y}$$

$$\text{e.g., } \mathbf{T} = \sqrt[4]{\frac{F}{\sigma}}$$

$$y = \begin{pmatrix} Z \\ \sigma_d \\ \beta \\ LWP \end{pmatrix}$$

G **for reflectivity:**

$$Z = \int_0^{D_{max}} D^6 N dD$$

Retrieval:
x: microphysics
y: remote sensing Obs.
G: math/phys. formulas

$$x = \begin{pmatrix} r_c \\ N_c \\ LWC_c \\ r_d \\ N_d \\ LWC_d \end{pmatrix}$$

Cloud

$$D_c = 20\ \mu m$$

Drizzle

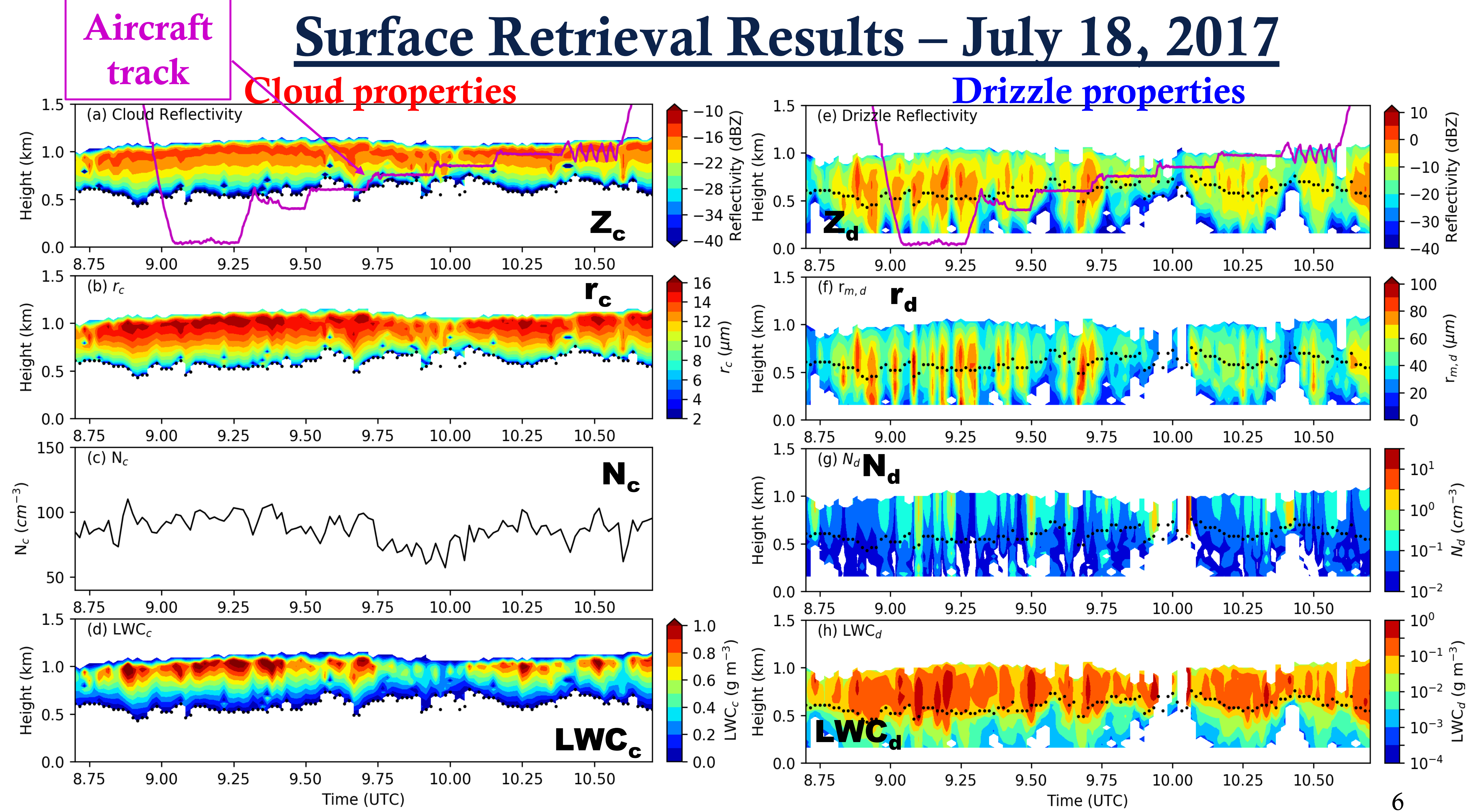
$$D_d = 150\ \mu m$$

$Z_{drizzle} >> Z_{cloud}$

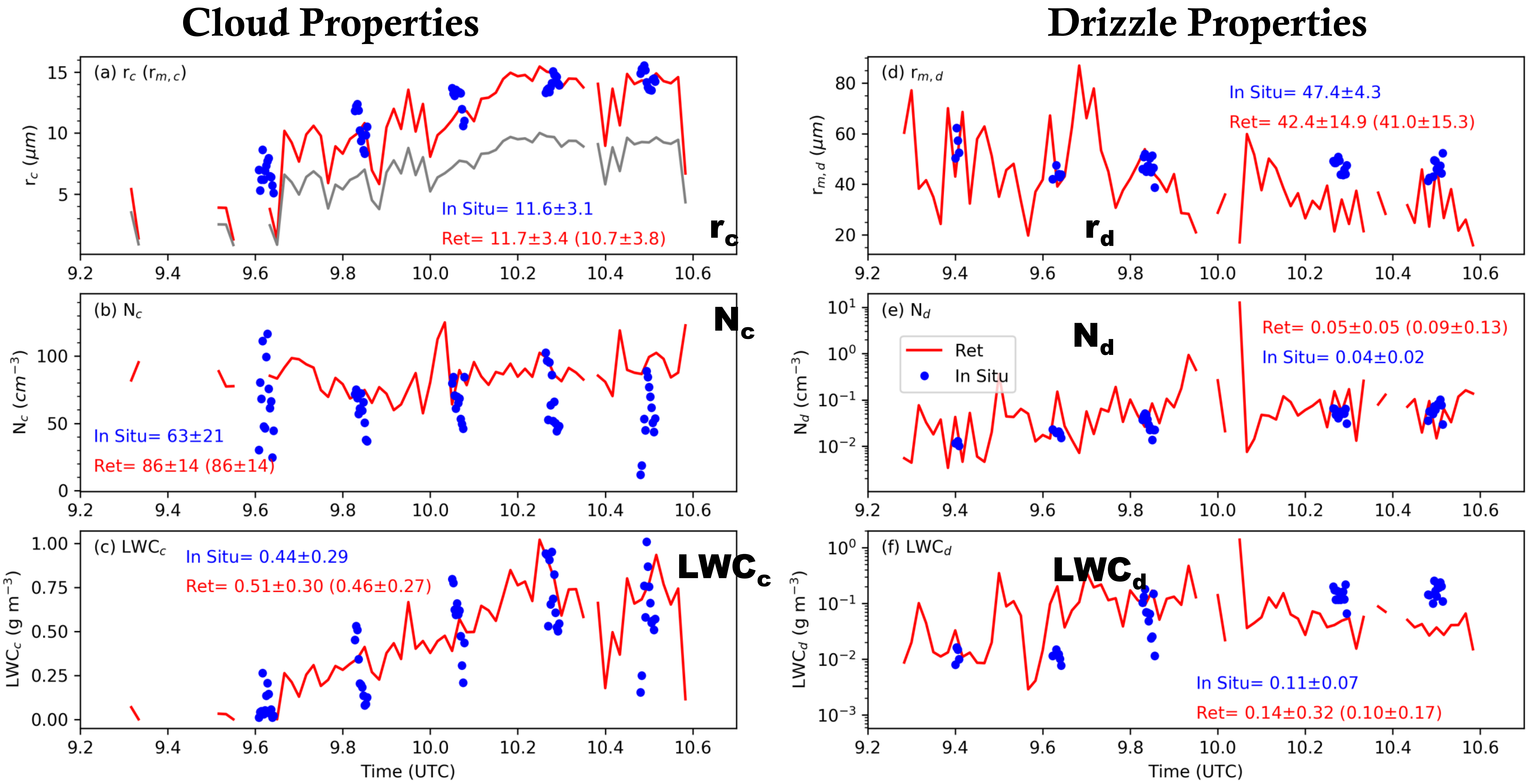
Assumptions:

1. Lognormal Dist. for cloud droplets and normalized Gamma Dist. for drizzle drops
2. Drizzle drop number concentration increase linearly from below to above cloud base
3. Cloud droplet number concentration does not vary with height

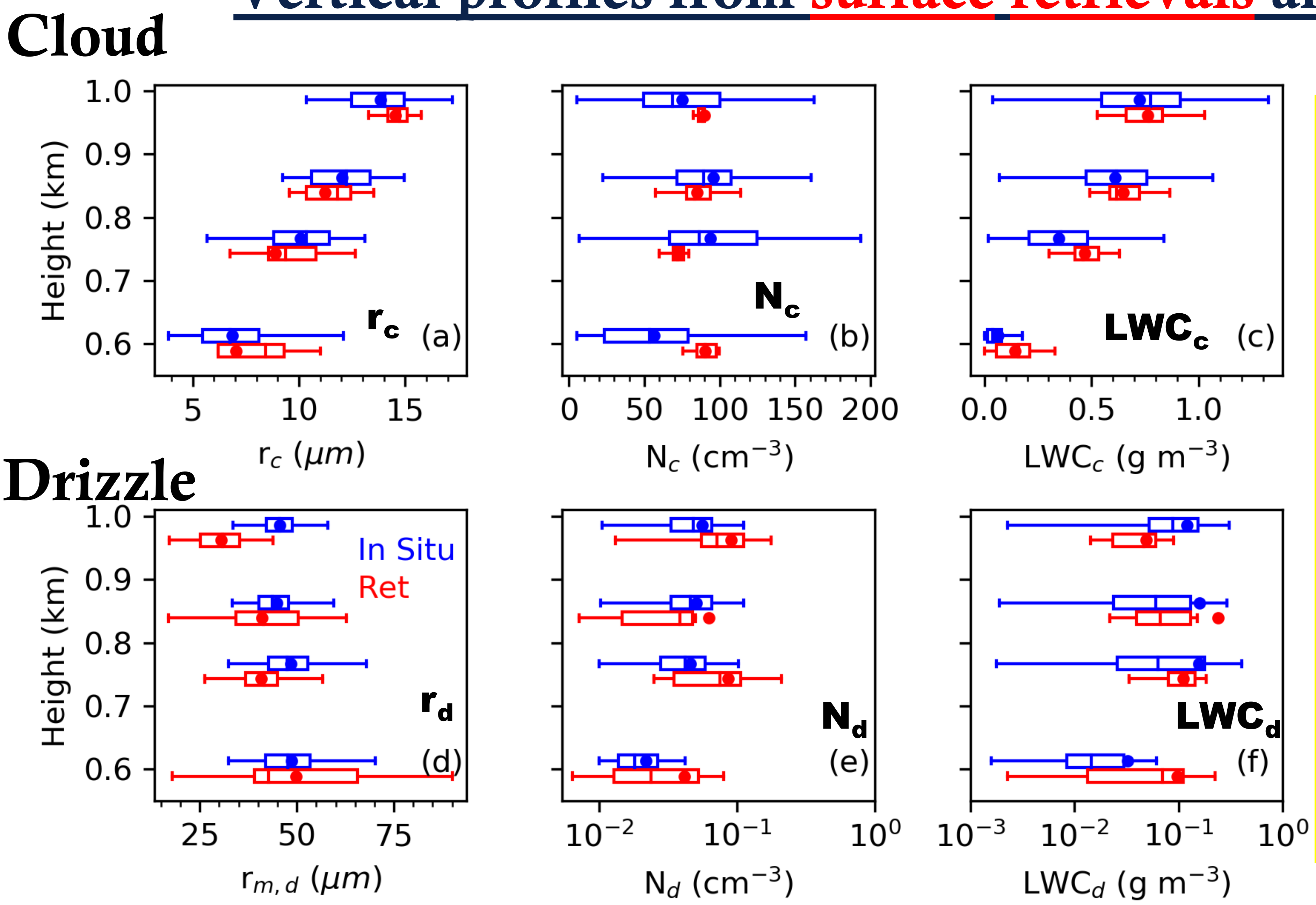
Surface Retrieval Results – July 18, 2017



Comparison of Surface Retrievals and Aircraft data



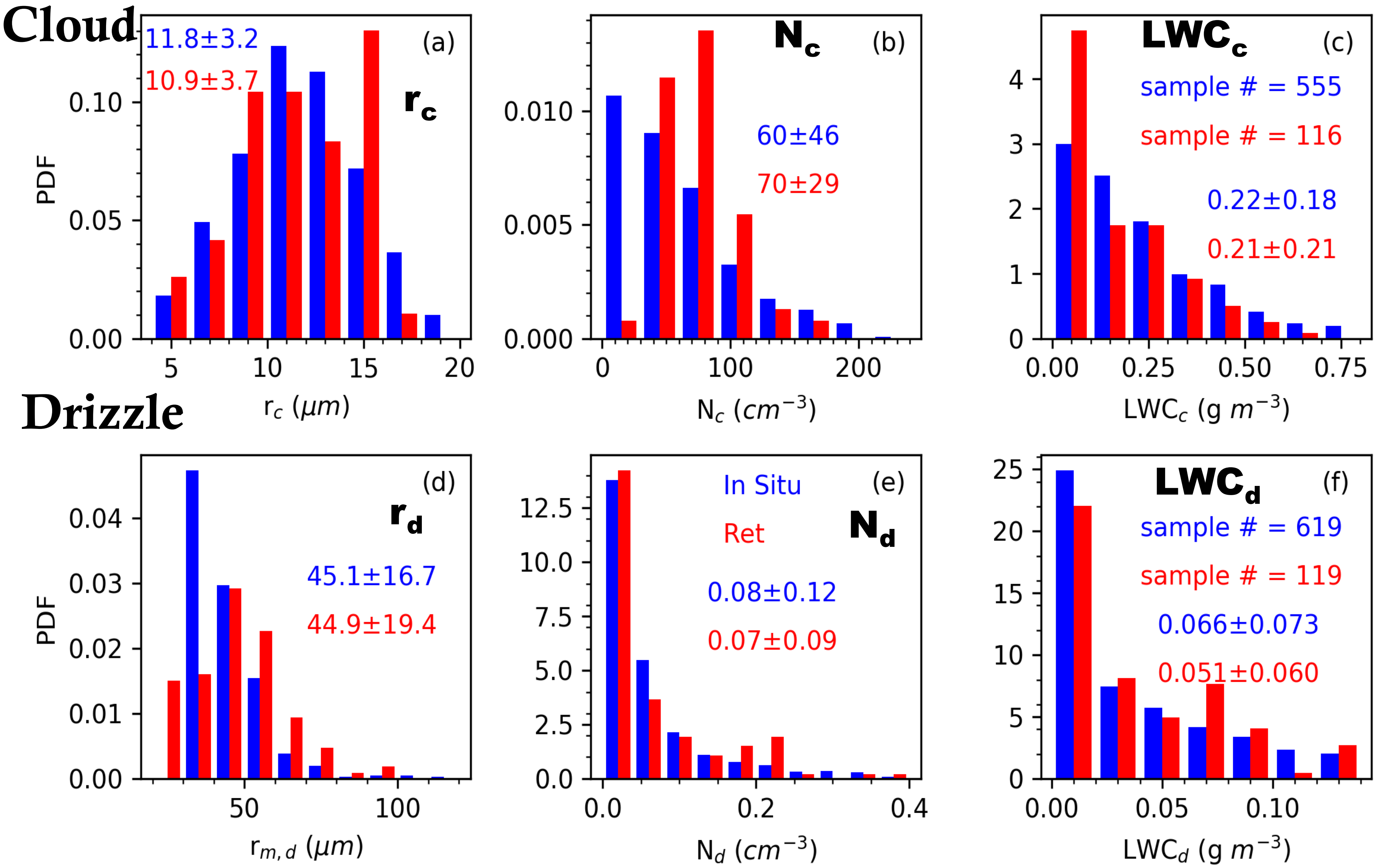
Vertical profiles from surface retrievals and aircraft data



- r_c and LWC_c increase from cloud base to top
- Drizzle drops form near cloud top with smallest size and highest concentration.
- As they fall, drizzle drops grow bigger towards the cloud base
- N_d decreases toward the cloud base
- From both time series and vertical profiles:

Good agreement between surface retrievals and aircraft in-situ data

All cases during ACE-ENA



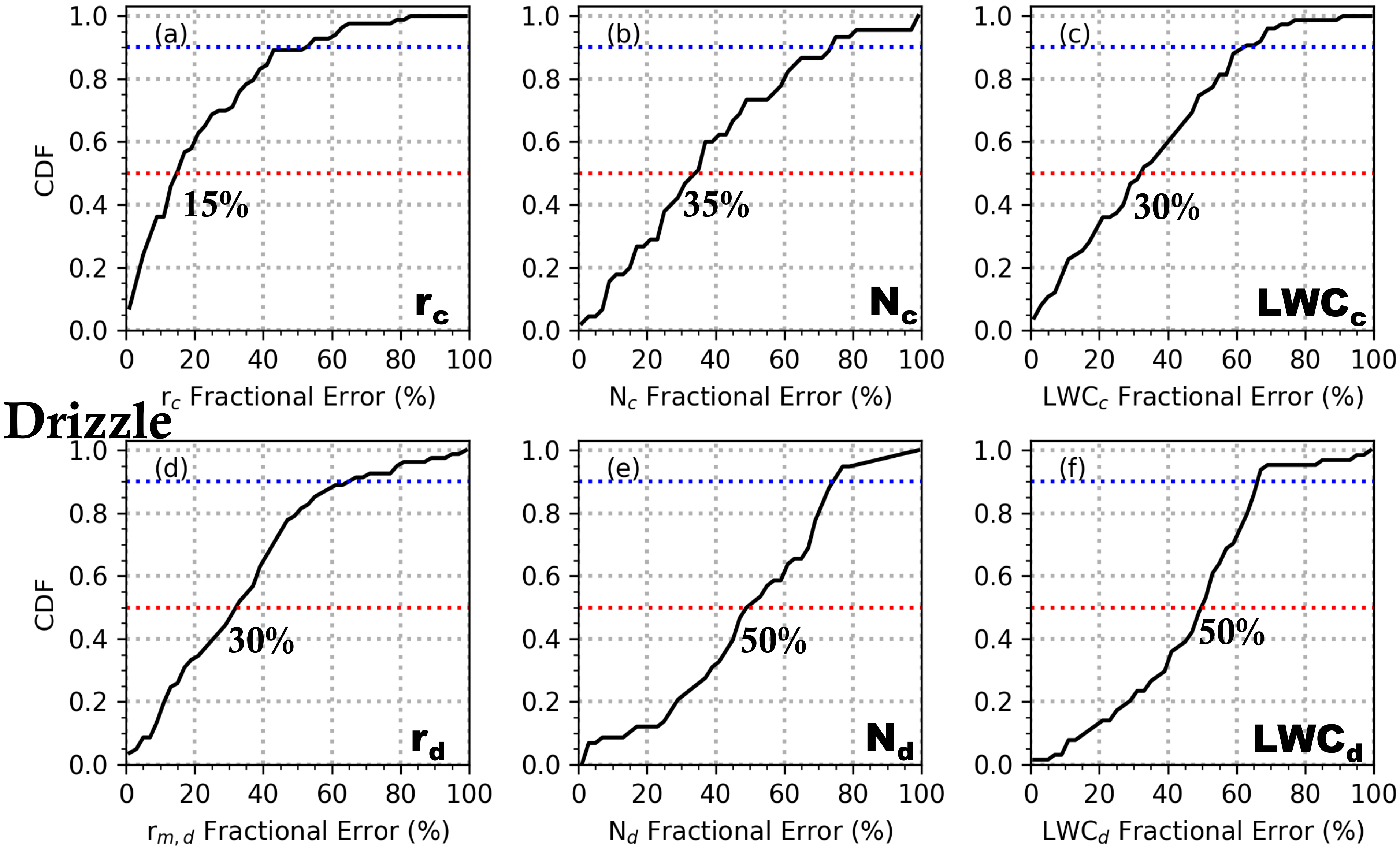
Surface retrievals can reproduce similar PDFs as aircraft measured ones

Negative retrieval biases except N_c

Surface Retrieval uncertainties

Cloud

Drizzle



$$\frac{|aircraft - surface|}{aircraft}$$

The retrieval uncertainties are estimated using aircraft data during ACE-ENA

Median retrieval errors are
~15% for r_c
~35% for N_c,
~30% for LWC_c, $r_{m,d}$
~50% for N_d, LWC_d

Summary (Part I)

- **Algorithm development**: retrieve cloud and drizzle microphysics profiles
- **Retrieval validation**: Collocated aircraft measurements
- **Median retrieval uncertainties** were ~15% for r_c, ~35% for N_c, ~30% for LWC_c, and r_d, and ~50% for N_d and LWC_d

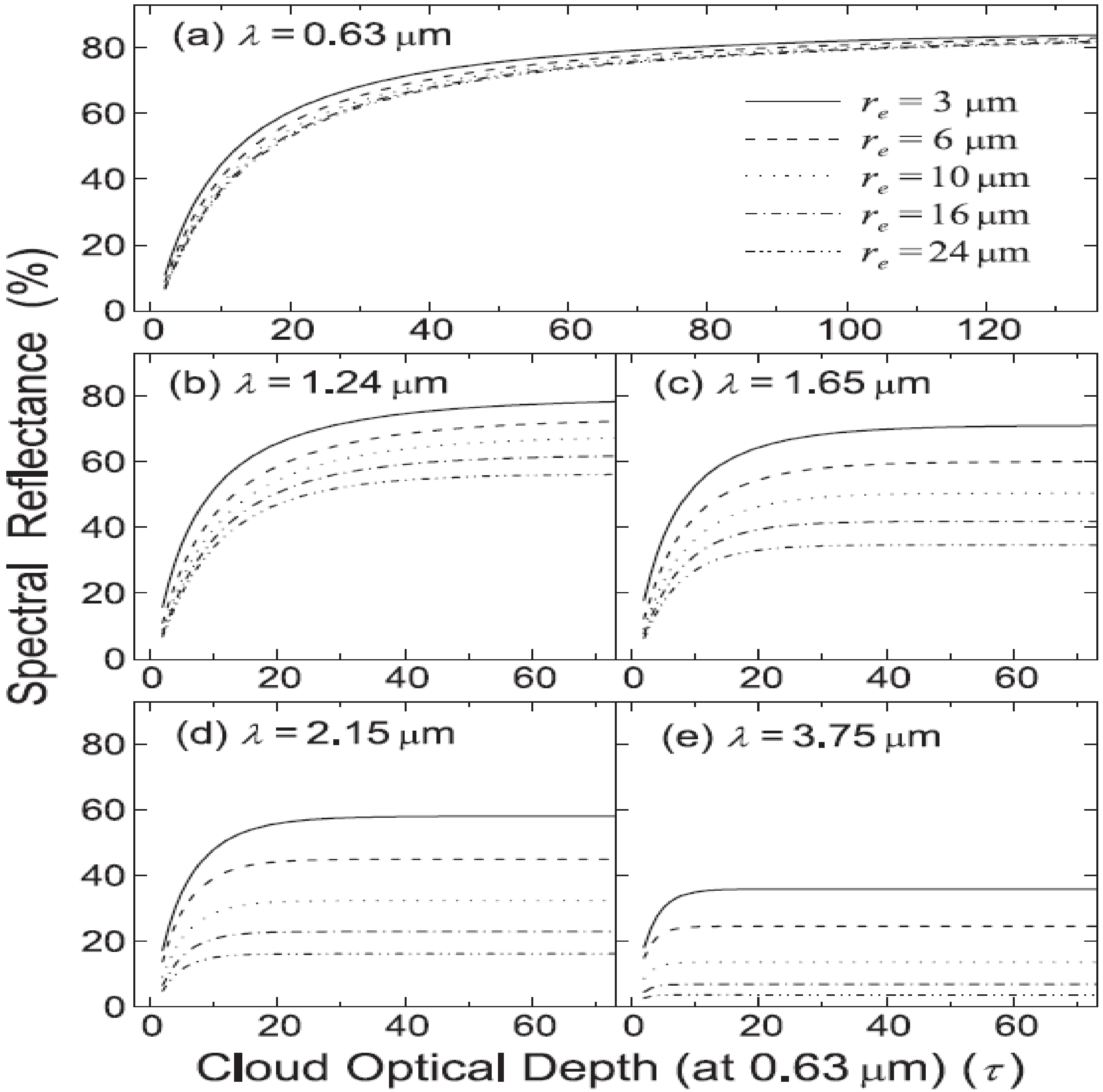
- r_c increase from the cloud base to z_i=~0.75 then decrease towards the cloud top, r_d monotonically increase from cloud top to cloud base then decrease below cloud base
- $r_d \approx 3{\sim}6\ r_c$
- $N_d \approx \frac{1}{1000} \sim \frac{1}{100} N_c$
- $LWC_d \approx \frac{1}{10} LWC_c$

Satellite Cloud Properties and Drizzle

Can the surface retrieval datasets be useful for understanding the relationships between the drizzle occurrence and intensity and the Re retrievals at different NIR wavelengths?

=> improving cloud Re and LWP estimates for CERES

It may also possible to retrieve the profile of MBL cloud microphysical properties using passive remote sensors, especially under drizzling conditions.



Chang and Li, 2002

➔**Potential for using a set of spectral retrievals.**

➔**Relies on reflectance at each NIR wavelength having unique sensitivity to r_e at different levels inside a cloud layer.**

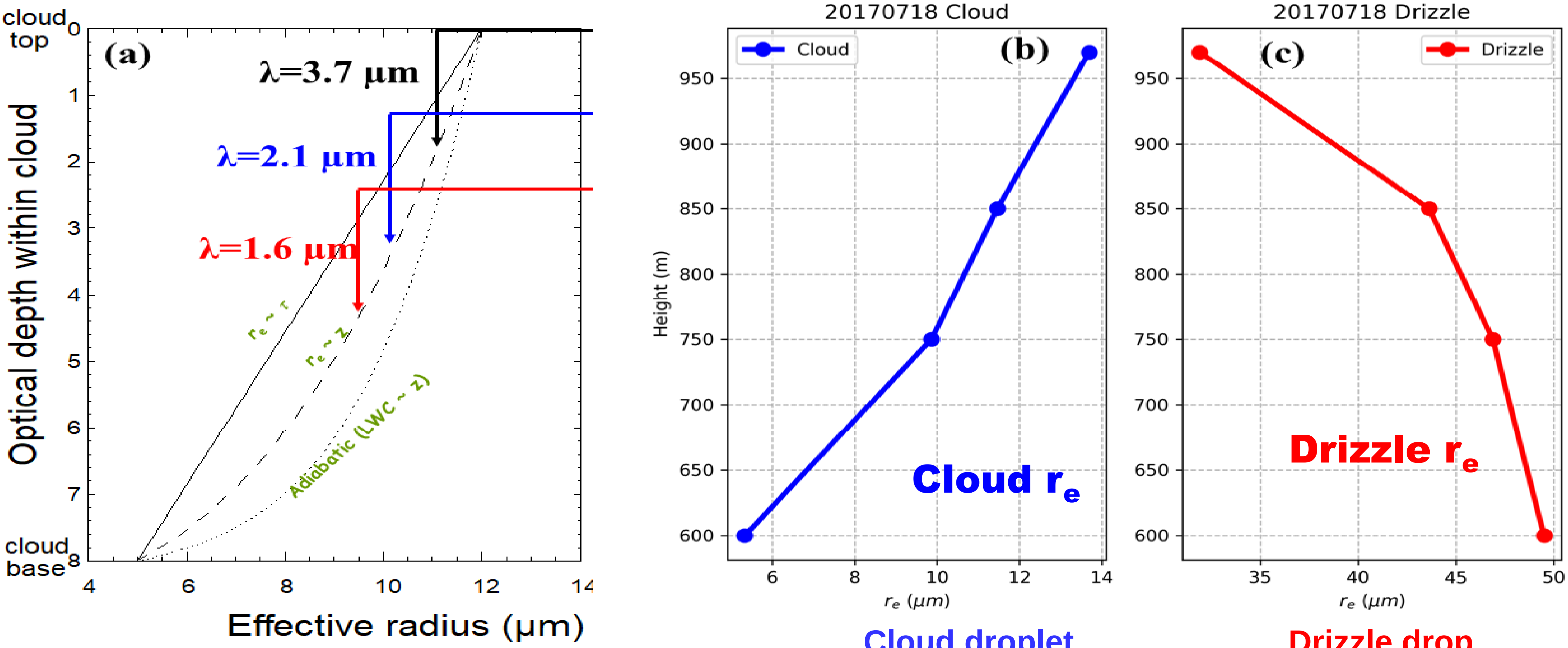
➔**Large cloud droplets absorb more solar radiation than smaller droplets, whereas smaller droplets can scatter more solar radiation than larger cloud droplets.**

➔**Reflectance at longer wavelength (λ=3.75 μm) saturates faster than shorter wavelengths (λ=2.15, 1.65 and 1.24 μm).**

➔**This is only for non-precipitating clouds**

➔**Chang & Li (2003) made first step to retrieving vertical profile of Re.**

Theoretically $r_e(3.7)>r_e(2.1)>r_e(1.6)$



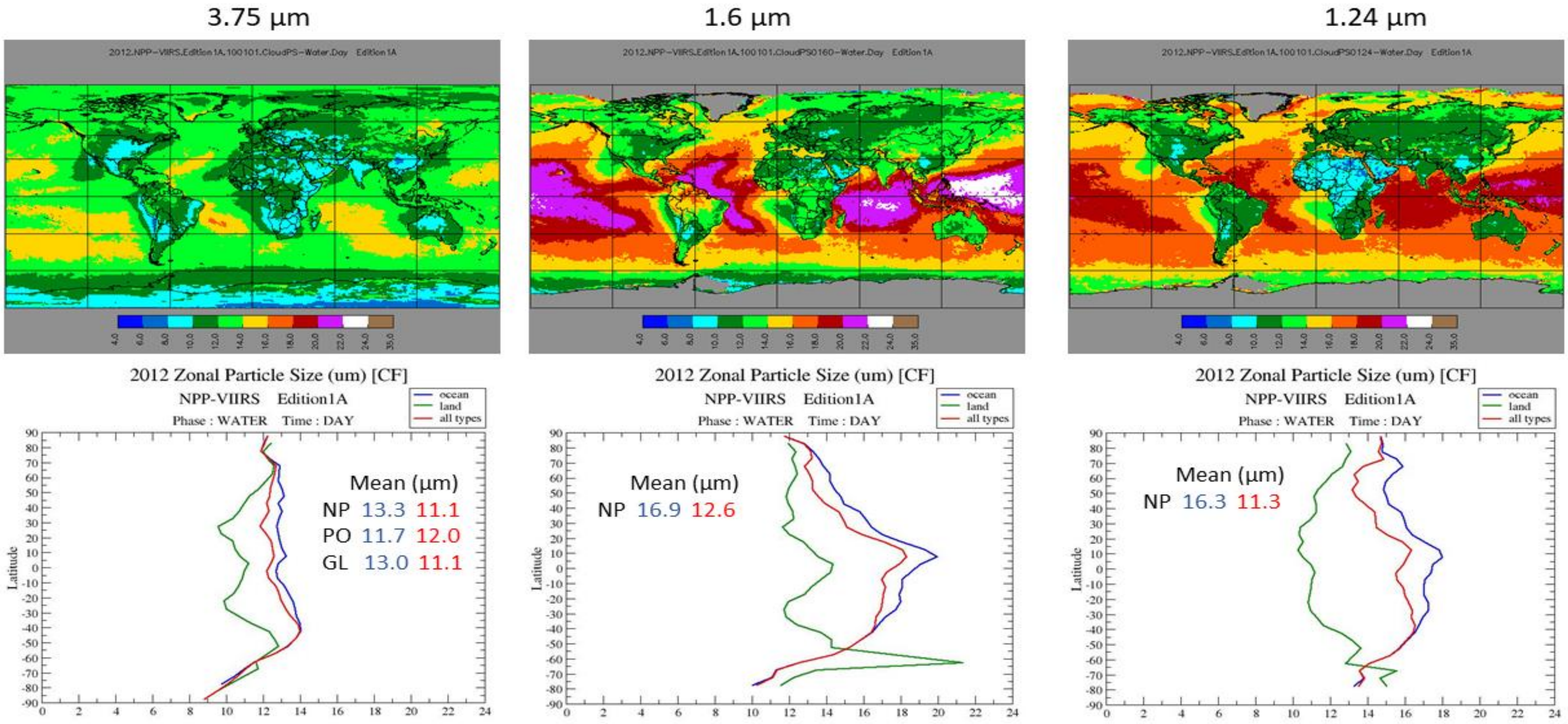
Platnick, 2000

Cloud droplet Drizzle drop

From Aircraft data during ACE-ENA

Most of the MBL cloud microphysical properties follow adiabatic growth with height. That is, $r_{e37} > r_{e21} > r_{e16} > r_{e12}$

Mean Water Droplet r_e from CERES VIIRS for 2012

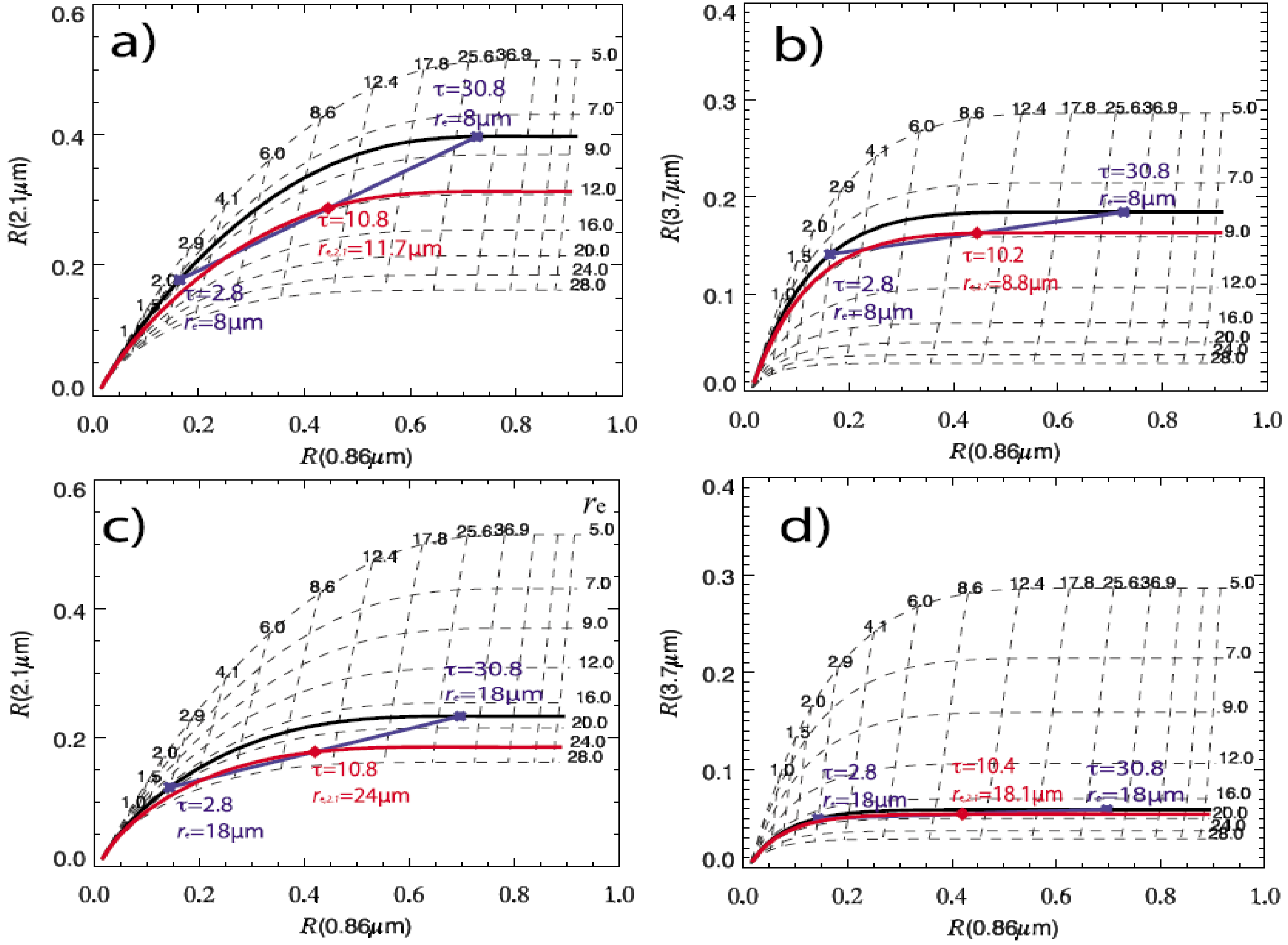


NP = Nonpolar, PO = Polar, GL = Global. 1.6 and 1.24 µm retrievals not performed over snow

However, satellite retrievals often fail to record adiabatic growth, that is, $r_{e16} > r_{e37}$, primarily due to drizzle.

r_e difference possibly due to horizontal inhomogeneity of cloud properties (Zhang et al. 2012, Zhang and Platnick 2011)

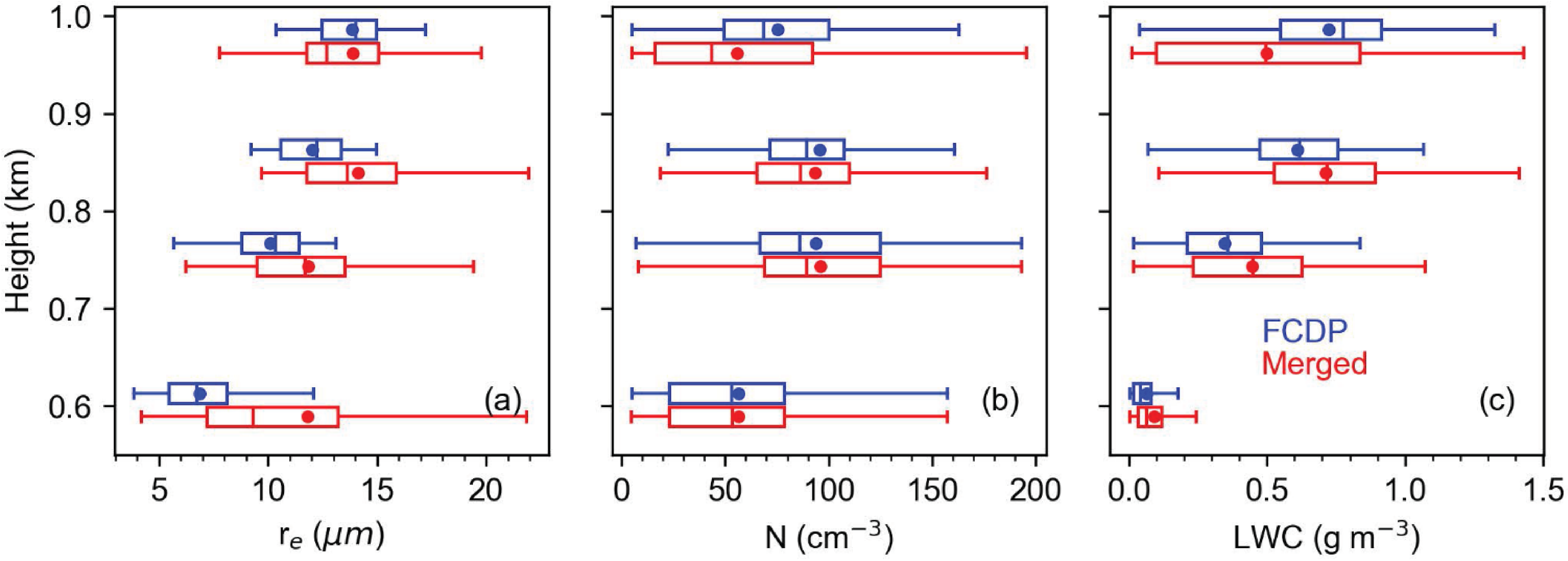
2.1 - µm channel **3.7 - µm channel**



Upper: non-drizzling case
r_{e21}=11.7 µm, r_{e37}=8.8 µm.
The nonlinearity leads to underestimation of tau (i.e., plane-parallel-albedo bias) and overestimation of r_e (i.e., plane-parallel r_e bias), affects r_{e21} more than r_{e37}, leading to larger r_{e21} than r_{e37} .

Lower: Drizzling case
r_{e21}=24 µm, r_{e37}=18 µm.
Overestimate r_{e21}, but not for r_{e37}.

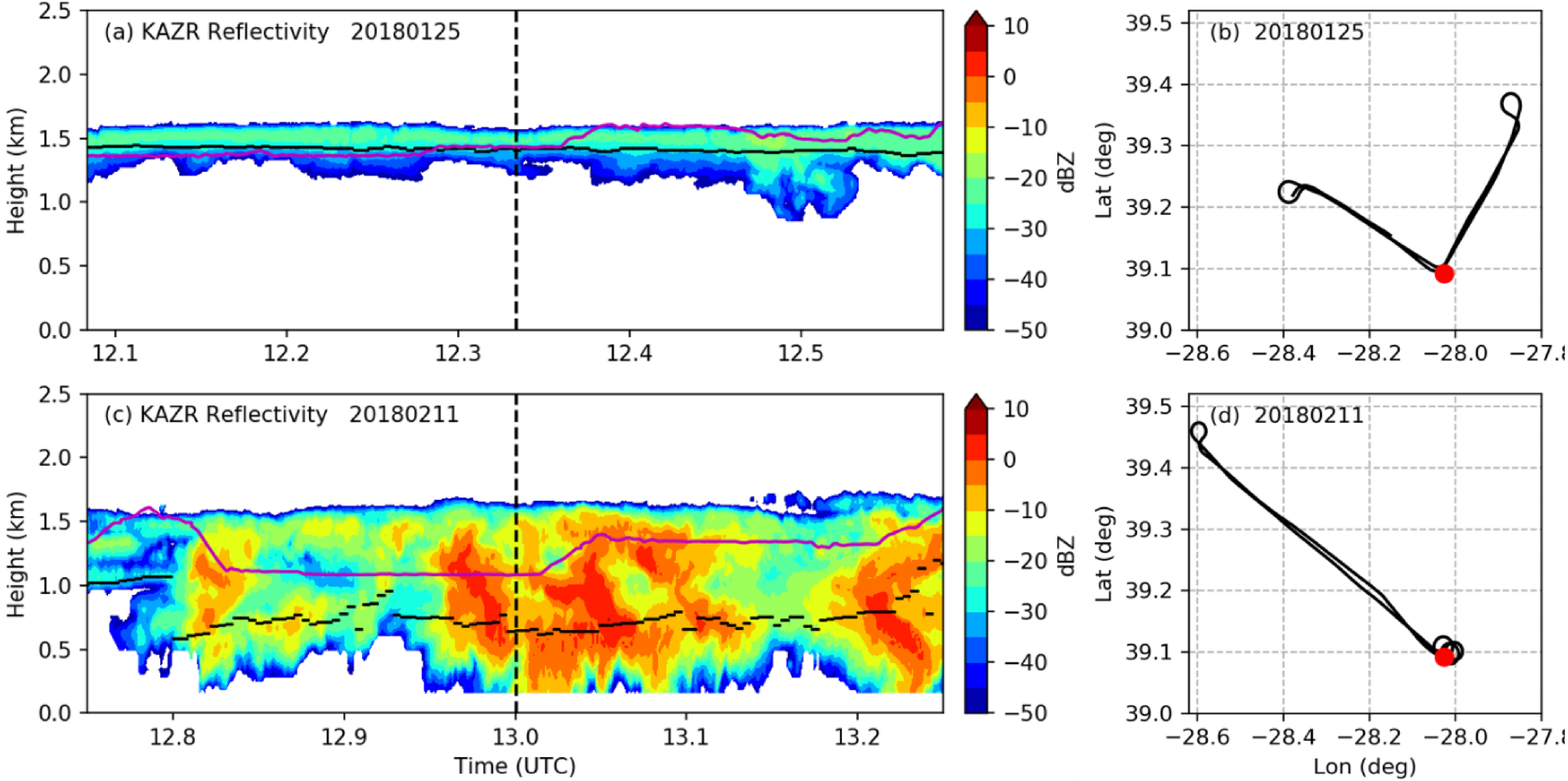
What is a "cloud truth" for r_e in a drizzling cloud layer?

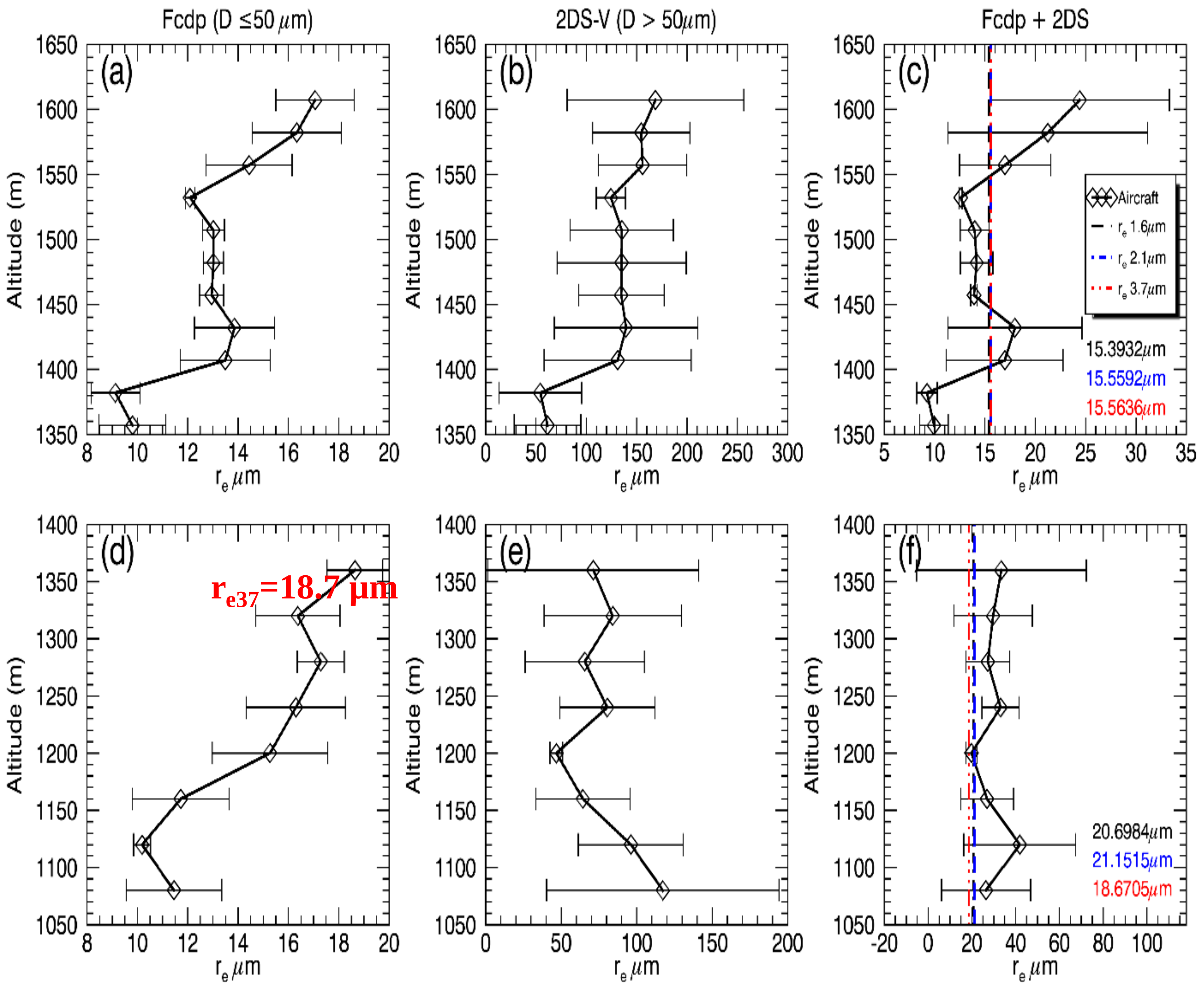


FCDP (2-50 µm), cloud droplets. Merged: FCDP+2DS (2-1000 µm), including both cloud droplets and drizzle drop.

Drizzle does not affect r_e near cloud top (for r_{e37}), but becomes more important toward cloud base (for r_{e21}, r_{e16}, r_{e12}).

Two cases: one for non-drizzle, one for drizzle during ACE-ENA





Upper: non-drizzling case

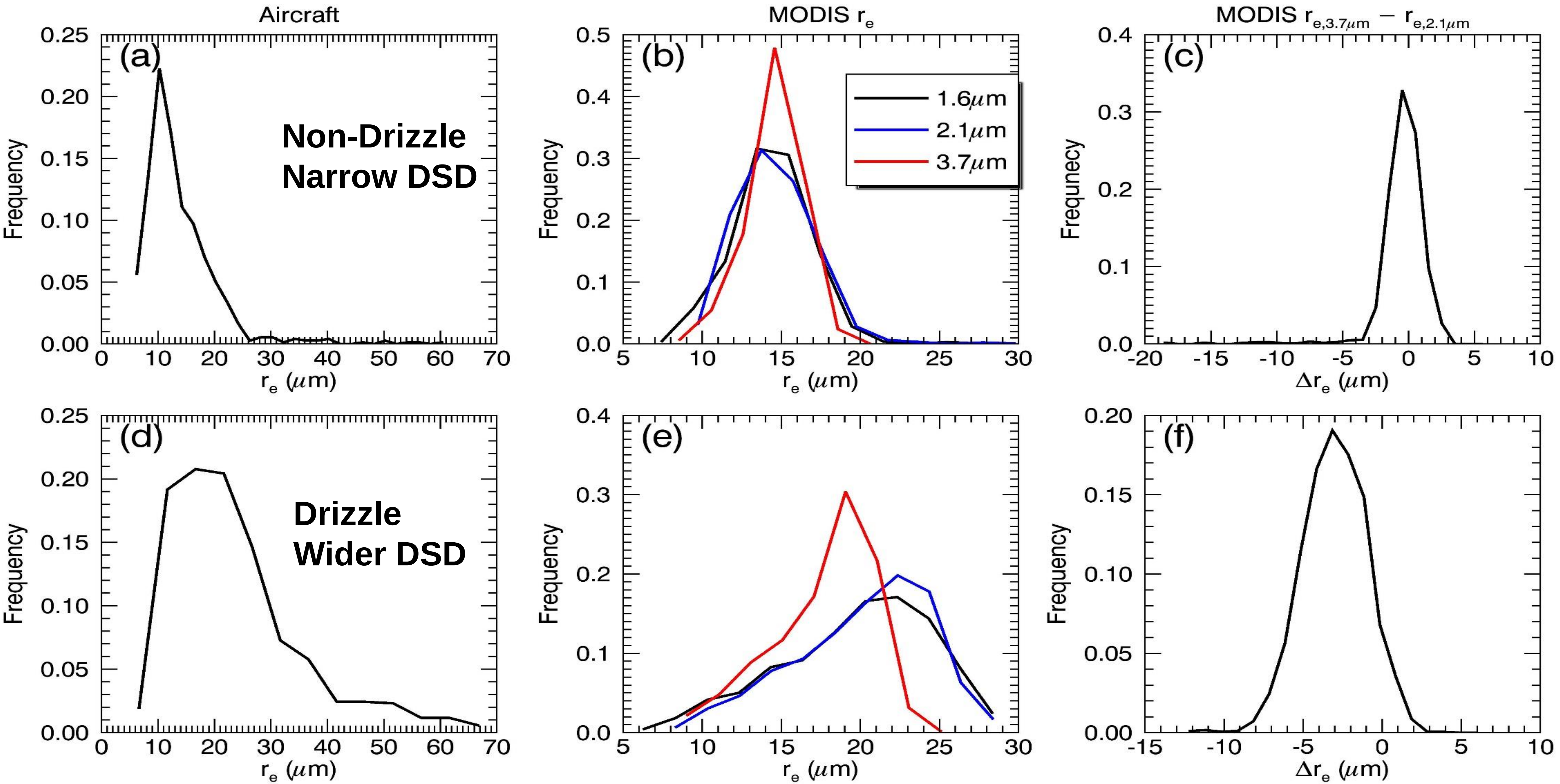
Although there are a few large drizzle drops, they contribute ~2 μm in Merged re, same as CM re retrievals ➔CM can capture MBL cloud microphysical properties under non-drizzling conditions.

Lower: Drizzling case

r_{e16}=22 μm, r_{e37}=18.7 μm. Smaller than merged r_e. Possible due to upper limit of r_e=30 μm for water clouds?

Bi-modal DSD?

Cloud DSD: left: Aircraft; Middle: Terra pixel; Right: r_{e37} - r_{e21}



Summary (Part II)

- A new method for quantifying drizzle properties (Nd and Re) has been developed using radar-lidar methods to separate drizzle and cloud droplet signals
- Method is validated with aircraft in situ data
- Results of the method, when matched with CERES $r_e(\lambda)$ retrievals, can be used to examine the relationships between r_e retrievals and drizzle, and should be supplemented with RTM computations using realistic droplet distributions
- This approach should permit the estimation of drizzle contribution to the r_e biases.
- In the long term, it should be possible to develop a method to estimate the amount of drizzle in the clouds observed by CERES

Using surface retrievals and aircraft in situ measurements as a ground truth to develop a new LUT for drizzle drop retrievals in CM Ed5. We understand this will need a lot of work, such as overcast vs. broken clouds, mono-modal DSD for non-drizzle vs. bi-modal DSD for drizzle, optical depth dependency, viewing and illumination angles etc.

Match the CERES Re with GPM precipitation to study cloud-precipitation processes, and MBL cloud radiation budget